URBAN JOINT FIRE SUPPORT: AIR FORCE FIXED-WING AND ARMY FIELD ARTILLERY PRECISION MUNITIONS CAPABILITES FOR URBAN OPERATIONS

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ABSTRACT

URBAN JOINT FIRE SUPPORT: AIR FORCE FIXED-WING AND ARMY FIELD ARTILLERY PRECISION MUNITIONS CAPABILITES FOR URBAN OPERATIONS, by Major Craig A. McCarty, 87 pages.

While both air and ground based fire support have proven themselves to be an invaluable and overwhelmingly lethal force in conventional combat, they have struggled to deal with the extreme complexity, density, and constraints of the Urban Operational Environment (UOE). However, it is in this area that precision munitions have proved their worth. The United States (US) Air Force's focus on precision munitions since the late 1960s has kept it a step ahead of the Army; however, the US Army has recently taken huge steps in the field of precision munitions and is in the midst of its own precision munitions revolution surrounding its Field Artillery (FA) capabilities. The integration of these newly fielded capabilities into the joint fight will strengthen US military capability, but will also pose a challenge to commanders, planners, and fire support coordinators to choose the right weapon for the right job. This thesis looks at a focused field of applicable Air Force and Army precision munitions, highlighting the advantages and disadvantages they have in urban combat. It researches the capabilities of each of the systems as they apply to urban operations with the intent of providing considerations to aid in employment.

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ACRONYMS

AAA	Antiaircraft Artillery
AO	Area of Operation
ATACMS	Army Tactical Missile System
BCT	Brigade Combat Team
BDA	Battle Damage Assessment
CAS	Close Air Support
CEP	Circular Error Probable
FA	Field Artillery
FM	Field Manual
FSCM	Fire Support Coordination Measures
GMLRS	Guided Multiple Launch Rocket System
GPS	Global Positioning System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ISR	Intelligence Surveillance and Reconnaissance
JDAM	Joint Direct Attack Munition
JFS	Joint Fire Support
JP	Joint Publication
JTAC	Joint Terminal Air Controller
LGB	Laser-Guided Bomb
LOS	Line of Sight
MANPAD	Man-Portable Air Defense

MEZ	Missile Engagement Zone
MLRS	Multiple Launch Rocket System
MOUT	Military Operations on Urban Terrain
OIF	Operation Iraqi Freedom
PGM	Precision-Guided Munition
SATCOM	Satellite Communication
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defense
SDB	Small Diameter Bomb
TLE	Target Location Error
UAS	Unmanned Aerial System
US	United States
UOE	Urban Operational Environment

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CHAPTER 1

INTRODUCTION

Introduction and Context

Today's military contemporary operational environment continues to revolve more and more around urban areas. Here, the enemy in the ongoing Global War on Terror has found a safe haven and an advantage among the extreme complexity and density of urban areas. Sheltered among or behind the innocent, they are well camouflaged, well connected, and only minutes away from their targets. The city has now become the enemy's preferred area of operations (AO), and they use its complexity to equalize the battlefield and to gain an asymmetrical advantage over United States (US) conventional military capabilities. One example of this asymmetrical advantage is the challenge the US military faces of effectively supporting ground operations through joint fire support (JFS). While both air- and ground-based fire supports have proven themselves to be an invaluable and sometimes overwhelmingly lethal force in conventional combat, they have struggled to deal with the constraints presented by the urban operational environment (UOE), particularly in the case of artillery. Multiple, independent, highly mobile targets spread thinly in high collateral damage areas makes JFS a significant challenge. The terrain, population, and infrastructure all combine to limit the effectiveness of conventional systems. Military technology, however, can offset some of the asymmetrical advantage given to the enemy in the UOE, and one of the most useful of these technologies is precision munitions.

Air-delivered precision munitions first debuted during the Vietnam War, and in the time since have become not only common on the battlefield but also the backbone of

air interdiction. In this area, the US Air Force paved the way for the other services with an "indirect fire revolution" (Scales 1995, 238). Although costly, these munitions eventually proved their worth as they approached the proverbial "one-shot, one-kill" capability. With precision munitions accounting for just 8.8 percent of bombs in Desert Storm in 1991, the total employed has jumped to over 70 percent in Operations Enduring Freedom and Iraqi Freedom (OIF) today (Lucas 2003, 10-11). A major factor driving their use is the focus on urban counterinsurgency operations, and the collateral damage concerns that go with them. These operations in Iraq continue to make air-delivered precision munitions and direct fire munitions the predominant weapons of choice.

As the value of precision munitions became readily apparent to the Air Force, the US Army also realized there was a huge benefit to pursuing the same capability for its Field Artillery (FA). With the introduction of Copperhead in 1981, the Army followed the Air Force's footsteps as it fielded its first artillery based precision-guided munition (PGM). Although it has taken time, the Army has since fielded a number of precision munitions. These weapons give the Army similar capabilities to the Air Force, thus muddying the waters on the optimal mix and application of these weapons in a joint environment. For operational and tactical planners, commanders, and fire support coordinators, understanding the capabilities of these munitions and their systems can be a daunting task, especially when applied to the complexity inherent to the UOE. For these planners and operators, the question becomes, What are the strengths and weaknesses of these systems, and how are they best applied together? This thesis seeks to provide answers to these questions.

Thesis Questions and Format

This thesis will research and compare the roles of US Air Force and US Army precision munitions capabilities and how they apply to JFS in the UOE. Specifically, it will attempt to answer the following question: What are the critical considerations for the joint employment of Air Force fixed-wing and Army FA precision munitions for urban fire support?

In order to achieve this, a foundation will be built from the following secondary and tertiary questions.

1. What constitutes the urban operational environment?

2. How does it differ from other environments from the perspective of fire support?

3. How would the desired effects differ?

4. What are the unique advantages and disadvantages of the weapons systems when applied to the UOE?

    a. Which systems have the necessary range?

    b. What are the risks associated with the various systems?

    c. Which systems provide the best responsiveness and persistence?

    d. Which systems are most accurate?

    e. Which systems are most flexible?

This research will compare a variety of ground- and air-based systems with the intention of understanding how precision munition JFS may be best employed in the UOE. In comparing the two systems, it is not intended to single out one platform as being better or worse than others. In fact, many direct comparisons will be deliberately avoided,

and instead, the analysis will focus on the capabilities of the systems and munitions in the UOE. However, it is necessary to understand the strengths and weaknesses of both fixed-wing and FA systems as they apply to the UOE and how they relate to each other. Only by doing this will commanders, planners, and targeting and effects cells have a better understanding of how to effectively employ these systems together.

In order to achieve this end state, this thesis is organized into five chapters. Chapter 1 provides an introduction to the topic, outlining the scope and specifics of the problem. Chapter 2 takes an in-depth look at the current state of literature on the topics of urban operations and Air Force and Army precision munitions. Chapter 3 defines the methodology used in the research, and chapter 4 summarizes the findings of the research itself. Finally, chapter 5 answers the research questions and provides recommendations for application and for areas requiring additional research. In order to define the specific areas of research for this thesis, the remainder of this chapter will establish a foundation based upon assumptions, definitions, limitations, delimitations, and the applicability of this research.

Assumptions

This thesis is built on the primary assumption that the literature and information available will provide a valid understanding of Air Force and Army systems and their emerging capabilities at the unclassified level. Additionally, the research is based only on existing and emerging technology and weapons systems discussed herein. Future technological developments and new weapons systems could and quite possibly may alter the conclusions.

Definitions

Most of the proposed thesis will include commonly understood or doctrinal definitions of applicable terms. The basis for these will be specified when able. However, there are also terms for which definitions vary from service to service, terms which doctrine leaves room for interpretation, or terms where doctrinal definitions do not apply for the purposes of this research. These have been defined by the author. A handful of both doctrinal and thesis specific terms, which constitute a foundation for understanding the research and propositions, are defined below.

Circular Error Probable (CEP). An indicator of the delivery accuracy of a weapon system, used as a factor in determining probable damage to a target. It is the radius of a circle within which one-half of the munitions are expected to fall (Department of Defense 2001, 86). The CEPs noted in this thesis are the nominal, unclassified specifications which the munition is physically capable of under most circumstances. It is important to note that, as with any weapon system, a munition's accuracy depends on a variety of factors. For the precision munitions discussed herein, factors, such as aircrew and artillery crew training, space and terrestrial weather, hardware failures, and improper coordinates, among other reasons, can reduce this accuracy.

Fires. The use of weapon systems to create a specific lethal or nonlethal effect on a target. The Joint Publication (JP) 3-0 definition encompasses targeting, JFS, offensive counterair, interdiction, strategic attack, electronic attack, and network defense (Department of Defense 2006a, xvii). However, this thesis will only cover JFS.

Joint Fire Support (JFS). JFS is defined as joint fires which assist air, land, maritime, and SOF to move, maneuver, and control territory, populations, airspace, and

key waters (Department of Defense 2006b, vii). This usually encompasses a variety of systems from helicopters, fighters, and bombers and their associated weapons, to electronic warfare platforms, mortars, artillery, and surface-to-surface rocket systems.

Precision Munitions. Joint doctrine currently has no definition of precision, as it relates to weapons accuracy. The only distinct references are in JP 1-02 where "precision bombing" is defined as bombing directed at a specific point and a sentence in JP 3-09.1 which refers to laser-guided munitions as precision weapons (Department of Defense 2001, 1999). Unfortunately, this does little to provide terms or guidelines for classifying munitions according to their accuracy. Underlying this is the fact that the services have varying nondoctrinal definitions for the term and thus different, with sometimes no specific requirements for the classification of precision weapons. The Air Force has no doctrinal definition of precision; however, it is commonly accepted and taught at the USAF Weapons Instructor Course that precision means a 3 meter or less CEP, and accurate means a 13 (nominally referred to as 10) meter or less CEP (Sine 2006, 81). The Army uses the term precision frequently in doctrine, but also fails to define it formally, although in a recent interview, Major General David C. Ralston, US Army Chief of Field Artillery, stated, "We define precision as under 10 meters [CEP]" (Gourley 2006, 60). According to the varying field manuals (FMs), the Army considers its laser guided weapons to be precision systems, but also considers some unguided artillery systems to have limited precision capability. This is probably a dated use of the term since until recently the Army had few fire support munitions capable of an accuracy of 13 meters or less and currently has limited capability to achieve a CEP of 3 meters or less. Therefore, for the purposes of this thesis and only in the interest of including global positioning

system (GPS)-aided munitions when comparing Air Force and Army munitions, the following definition will apply: The term precision munition will refer to a weapon that can achieve a CEP of 13 meters or less. (Note: This is “not” a proposition for a new joint service or other definition of precision). These precision munitions may include: laser guided weapons, such as Paveway series laser-guided bombs (LGBs) and Copperhead; and GPS-aided munitions, such as joint direct attack munition (JDAM), guided multiple launch rocket system (GMLRS) Unitary, Army tactical missile system (ATACMS) Unitary, and 155-millimeter Excalibur.

Precision-Guided Munition (PGM). A weapon that uses a seeker to detect electromagnetic energy reflected from a target or reference point and, through processing, provides guidance commands to a control system that guides the weapon to the target (Department of Defense 2001, 423). It is noteworthy that this definition excludes GPS-aided munitions and does not define a minimum CEP or target effect to be achieved. For this reason, the term PGM will generally be avoided in this thesis, and the combination of PGMs and GPS-aided munitions will be referred to collectively as precision munitions.

Urban Operational Environment (UOE). The environment, factors, and conditions in urban areas which must be understood to complete the mission. These include a three-dimensional man-made physical terrain, a noncombatant population, and the physical and service infrastructure (adapted from JP 3-06). For the purposes of this thesis, urban areas constitute any terrain in which man-made structures are the predominant landscape features, and the location, proximity, and congestion of these features restrict, channel, and limit conventional military fires and maneuver.

Limitations

This thesis covers Air Force and Army precision munitions and how they apply to the UOE. Due to security classification requirements, discussions of emerging Air Force or Army technology, and certain tactics and procedures in the thesis are limited. Additionally, due to budgetary limitations, the research was physically conducted in the immediate area surrounding Fort Leavenworth, Kansas. Because of this, research was primarily obtained from secondary sources; however, primary sources were used where and when it was possible. Finally, while Air Force precision weapons have been fielded since the Vietnam War, the emergency of viable FA precision technology is a fairly recent trend. Due to this, the availability of historical data on the use and performance of FA precision weapons was extremely limited.

Delimitations

The topics of precision munitions and urban operations are a broad area of study and must be narrowed in several ways for the purposes of this thesis. First, there are distinct differences between the use of these munitions in close proximity to and in support of the movement and maneuver of friendly forces and their use for interdiction or deep strike. To keep the research within the scope appropriate for a master's thesis, this paper is written toward the targeting staffs in the Fires and Effects Coordination Cell, commanders, Air Liaison Officers, and Joint Terminal Air Controllers (JTACs) at the Division level and below and is focused on lethal fires only. It is assumed that most future urban military operations will involve fielded troops on the ground and that lethal fires in these operations areas will involve troops in contact and in close proximity to the field of fire. Therefore, this thesis only covers lethal precision munitions used in JFS

(Close Air Support (CAS) and organic and direct support artillery fires). This delimits fires, such as air interdiction, deep strike, or other missions which are not directly supporting or in close proximity to friendly troops on the ground. The availability of unmanned aerial systems (UASs) and the ability to employ weapons from them have developed rapidly, even during the course of this research. Although UASs are used to conduct specialized missions in close proximity to ground personnel, they remain an intelligence, surveillance, and reconnaissance (ISR) asset and are not apportioned or distributed as CAS to the ground commander. It is clear, though, that this may change in the future. However, due to the difficulty of delineating Air Force and Army UASs in the context of the thesis and given their current role as ISR assets, UASs and their specific munitions (Hellfire and Viperstrike) were not included in this research.

Second, this thesis does not address weapons with a warhead size of over 500 pounds, including MK-83 and MK-84 class bombs, ballistic missiles, cruise missiles, or other strategic strike type weapons and their application to urban operations. This is due to space and time available as well as their limited applicability to limited warfare in the UOE directly supporting troops.

Third, in order to define the research question narrowly, the research focused only on Air Force fixed-wing and Army FA munitions. While it does not necessarily include specifics applicable to other service, many of the munitions do have commonality between services, a good portion of the research may be applicable to the Marine Corps or Navy. Additionally, this delimits Army rotary-wing aviation and their munitions as well as mortar fires, although they do or will offer excellent precision capability in the urban environment.

Last, it is necessary to differentiate between direct fire gun systems and precision munitions to define the scope of this thesis. Numerous direct fire, cannon, or rifle systems utilizing unguided munitions (such as those employed on the AC-130) have an accuracy of less than 13 meters and are extremely valuable assets for conducting urban operations. However, the countless number of these systems, along with their differences in application, precluded their consideration in this research due to space.

Significance of the Study

According to a 2000 Air Force study, "Global urbanization, particularly in the developing world, makes it likely that many--if not most--future military operations will have an urban component" (Vick et al. 2000, xiv). Since that study, military operations in urban terrain (MOUT) have consistently become a part of recent conflicts and are most recently a definitive part of Global War on Terror operations in Iraq. Numerous studies, research papers, theses, and other documents centered on urban operations have been written in recent years, much of these discussing the use of precision fires and munitions at a service (Air Force or Army) level. While service specific writings are necessary and beneficial, recent history has consistently demonstrated that joint engagement can create synergistic effects which allow the military to achieve battlefield dominance. However, along with this capability comes an increase in complexity involved with coordinating the planning and execution among the separate services.

Each of the services brings to the fight a plethora of tools to choose from in planning and executing a campaign. The knowledge required of the field commander, targeting cells, and staffs to correctly apply these tools is constantly growing with the addition of each new weapon system or capability. The intent of this thesis is to provide

those cells, commanders, and planners critical considerations for joint precision munitions applications in the close fight on an urban battlefield. This thesis looks at a focused field of applicable Air Force and Army precision munitions, highlighting the advantages and disadvantages they have in urban combat. It looks at the capabilities of each of the systems as they apply to urban operations with the intent of providing considerations to aid in employing the right munition for the given mission. As Army precision munitions capabilities are just beginning to emerge and be fielded, there currently exists little research which compares the application of Air Force and Army precision munitions capabilities. This thesis attempts to fill this void, using service-specific literature on the topics of urban operations and precision munitions as a basis.

CHAPTER 2

LITERATURE REVIEW

In recent years the US military has been increasingly involved in urban conflicts. In the 1990s alone, US forces were directly involved in at least nine major operations in urban areas (Department of the Army 2002, 1-8). From recent operations in Bosnia, Haiti, and Mogadishu, to the ongoing battles in Baghdad and Mosul, the services' interest in the urban environment and ways to mitigate collateral damage in these areas has been nearly insatiable. As a result, the breadth of literature available on precision munitions and urban operations in particular is plentiful. Research for this thesis looked at current service and joint doctrine in the form of FMs, JPs, and tactic and technique pamphlets, as well as government research projects, government reports, military student theses, and civilian literature in the form of journal and news articles.

The beginning of this chapter provides a list of relevant literature sources researched for this thesis, and their topics. The remaining portion summarizes the current state of the literature as it relates to three areas: the urban environment and its effects on precision munitions and JFS; the development and current state of fixed-wing precision munitions; and the development and current state of field artillery precision munitions.

Relevant Literature

The recent interest by the military in the urban environment has given rise to numerous writings about urban operations, urban constructs, and military operations therein. Of note on the topic of general military operations in urban areas are a series of books by RAND, which include *Mars Unmasked: Changing the Face of Urban*

Operations (2000) by Sean Edwards, *Marching Under Darkening Skies* (1998) by Russell W. Glenn, and multiple volumes written by Russell W. Glenn and others summarizing urban operations conferences and concepts. The topics of these books generally center on the relevance of the UOE, the development of urban operations doctrine and constructs, as well as combat and training concepts for MOUT. Of particular note concerning fixed-wing precision munitions is another book published by the RAND Corporation titled *Aerospace Operations in Urban Environments.* This book provides an in-depth exploration of urban operations as they relate across the full spectrum of aerospace operations.

While these books do not directly relate to precision munitions and their use in the UOE, they do provide a foundation for understanding urban warfare. In fact, many of these books are the result of a military research contract with the RAND Corporation which, along with the US Marine Corps Warfighting Publication 3-35.3, and US Army FM 90-10, laid the groundwork for developing the Department of Defense's first joint doctrine document on the Joint Urban Operations, JP 3-06 (Glenn 2000, 379-473). In addition to JP 3-09, each of the services has recent doctrine covering MOUT, and urban considerations have been added to multiple other JPs, FMs, and multiservice manuals.

While most of the literature on urban operations has made its way into books, literature specific to Air Force and Army precision munitions is mostly confined to journals, magazines, and professional publications. Much of this is probably due to the fact that precision munitions are continually developing, and their application to limited warfare in the UOE is a new trend. Additionally, with the exception of Copperhead, the Army's use of precision munitions in indirect fires is a new development.

Currently, there is very little literature that specifically addresses Army precision fires in urban operations. However, the applicability of unguided FA to urban operations has been fairly widely studied and highlights some shortcomings. On the topic of general history of FA in urban operations is a monograph written by Major Wayne C. Greime Jr. in 2000 titled “Heavy Artillery: Military Operations in Urban Terrain (MOUT).” Another historical look at FA was “Artillery in Urban Operations: Reflections on Experiences in Chechnya,” written by Major Richard Wallwork in 2004. This thesis provides good background information on the applicability of artillery and lessons learned from the Soviet experience in urban areas during that conflict. A more contemporary-focused thesis, written in 2005 by Major Christopher Kidd, is “Army Direct Fire Accuracy: Precision and its Effects on the Battlefield.” It centers on direct fire accuracy, but does discuss indirect fire precision innovations in general terms. Writings specific to Army FA precision munitions were generally found in journals, news clips, and on-line articles.

On the subject of Air Force precision munitions in Urban Operations, much of the literature outside of books also included postgraduate writings. A thesis titled “Fire in the City: Airpower in Urban, Smaller-Scale Contingencies” was written in 1999 by Major J. Marcus Hicks. It researches the role of all aspects of airpower in urban operations, but provides some good information on the use historical use of fixed-wing precision weapons. “The Long Search for Surgical Strike,” written in 2001 by Dr. David R. Mets, also looks at the history of Air Force precision munitions. A thesis written in 1998 by Major Timothy L. Saffold titled “The Role of Airpower in Urban Operations: An Airman’s Perspective,” takes an operational and strategic look at the effects airpower can have on the UOE in general.

Finally, of note among both Air Force and Army sources, is a 2006 US Army Command and General Staff College master's thesis titled "Army Tactical Missile System and Fixed-Wing Aircraft Capabilities in the Joint Time-Sensitive Targeting Process" written by Major Henry T. Rogers III, USAF. In his thesis, Major Rogers does an outstanding job of comparing the two capabilities as they apply to the time sensitive targeting process, and his methodology provided a motivator for the development of portions of this thesis. The similarities of the two topics, albeit applied to different concepts, provided a starting point for the development of the methodology and analysis. Additionally, Major Rogers' developed an excellent attack guidance matrix which, to his credit, was reproduced in this thesis and applied to the topic of urban operations.

The Urban Environment

While there was a time that doctrine preached avoiding urban areas at all costs, increasingly, today's military operations are not only involving urban areas, but actually centered around them. The world's urban areas are prolific, especially in modernized countries, and they are growing. According to a 2005 United Nations report, 48.7 percent of the world's population resides in urban areas, and by the year 2030, that percentage is expected to reach 59.9 percent--an increase of 1.7 billion people (2006). This swell in urban living gives rise to more infrastructure, more urban landscape, and centralizes many of the enemy critical facilities and vital resources which will be engaged when military conflict is necessary. Unfortunately, the environment housing these centers of gravity, and the enemy, is immensely complex. The recent interest by the military in the urban environment has given rise to numerous attempts to categorize this terrain, and provide a framework for understanding and planning. The military answer to this

problem is found in JP 3-06, which defines urban areas by three constructs, called the urban triad: the population, the urban terrain, and the infrastructure (Department of Defense 2002, I-2). Each of these constructs considerably affects targeting and precision fires in urban areas, and they are thoroughly intertwined and reliant on each other. Of primary importance among these constructs when it comes to military action is the urban population--specifically noncombatants and their safety.

Both the Law of War and the now strategic "CNN factor" weigh heavily on the use of military force in urban areas. While today's enemy largely disregards the Law of War, the US is both morally and legally bound to operate within its constraints. The US is obligated to abide by laws which prohibit "an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated" (Department of the Army 2005b, 166). As important as the Law of War is to weapons employment, of more consequence is the strategic effect of headline news images of dead, injured or suffering innocent civilians, resulting from military action, regardless if it is legal or not. An example of this was the bombing of Al Firdis Bunker during Operation Desert Storm in 1991. This attack, on a legal military target, resulted in the unintentional killing of 300 innocent Iraqi civilians using the bunker as a nighttime shelter, and was a strategic setback for coalition legitimacy in the war (Department of Defense 1992, 615-617).

By design, urban areas house a large population in a small physical space. The proximity of this population and the infrastructure which supports them gives the enemy the capability to shield themselves. They hide above, below, beside, and behind

structures, establishments or personnel which are safe from attack, either due to the Laws of War, or due to the strategic consequences of collateral damage. Attacking and destroying a building containing 300 innocent civilians for the purpose of killing 15 enemy soldiers probably does not meet the Law of War rules for proportionality, and thus provides a safe haven for the enemy. Additionally, even if the fifteen personnel were high-level officials, and the rules of proportionality were met, the strategic consequences of those casualties in the media may not be acceptable. Moreover, the time required for planners and effects cells to review the laws and approve the target still provides the enemy at least a short duration refuge. Today's enemy knows these laws and US military limitations, and they use them to their advantage. More and more, the military is turning toward precision munitions as a solution for this dilemma. However, while the use of precision munitions can offset some of the enemy safe-haven capability, their physical employment is still challenging. This is a consequence of the second urban construct, the urban terrain.

FM 3-60 describes the uniqueness of the urban terrain:

> Urban areas present an extraordinary blend of horizontal, vertical, interior, exterior, and subterranean forms superimposed on the natural relief, drainage, and vegetation. An urban area may appear dwarfed on a map by the surrounding countryside. In fact, the size and extent of the urban battlespace is many times that of a similarly sized portion of natural terrain. (2005, 2-3)

Multilevel structures found in urban areas provide a vertical dimension extremely rare in the natural environment. They create both interior and exterior spaces for operations, and the proximity of these structures to each other creates urban canyons, dead space, and line of sight (LOS) problems which interfere with munitions capabilities, and communications (see figure 1). Additionally, military operations not only have to contend

with multiple levels in buildings, which may house enemies, friendlies and civilians alike, but also with the supersurface and subsurface of the city. Rooftops provide vantage points over streets and are often linked, providing a convenient means of movement or escape. They are also ideal locations for man-portable air defense (MANPAD) and antiaircraft artillery (AAA), where they may be safe from attack due to the civilians living directly below. In the subsurface, city subways, sewer systems, and other underground pathways allow nearly invisible lines of communication and movement, and their location makes targeting and engagement extremely difficult without causing collateral damage to the structures above or the sewer system, water lines, and other resources which support the city itself.

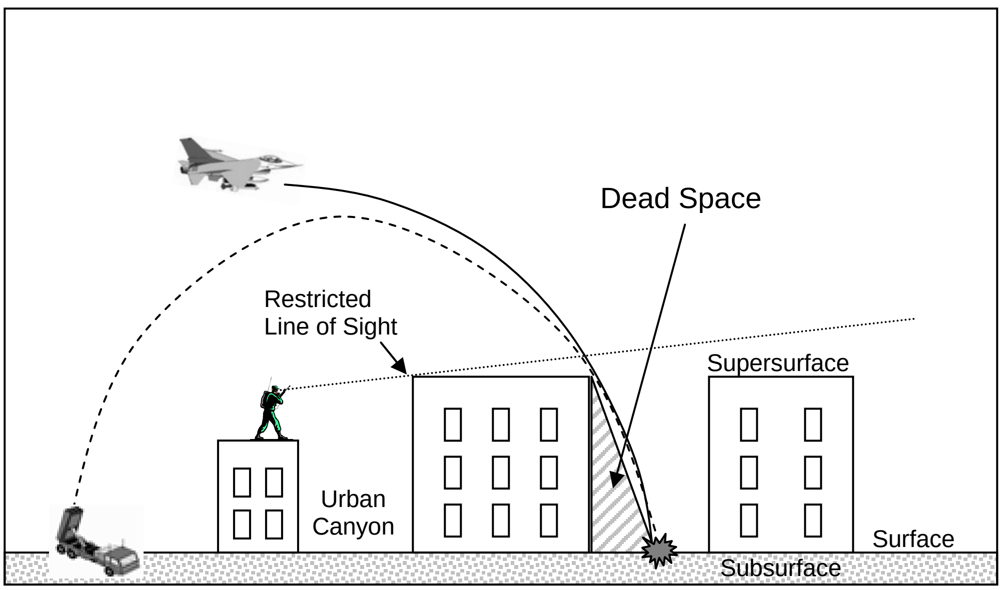

Figure 1. Urban Environment

In addition to the population and the terrain, the third urban construct is the vast network of infrastructure which supports the population. This includes, but is not limited

to, water supply, electrical, medical, academic, and trash systems, as well as police and firefighting forces. The Army's urban operations manual, FM 3-06, describes the interaction of infrastructure and military operations:

> [MOUT] may cause (either intentionally or not) uncontrollable fires or the loss of electricity. A power outage can cause flooding (especially in subsurface areas) by shutting down pumping stations. Entire buildings may be destroyed, eliminating reference points and leaving large piles of rubble. Additionally, buildings and other urban structures, damaged but not destroyed, can still be effective obstacles and possible booby traps. (2005, 2-3, 2-4)

Damage to city infrastructure, systems and public works, can create unintended and unacceptable effects on the resident population, and thus present an obstacle to the use of joint fires. While this collateral damage factor may be present in any number of operational environments, the physical congestion and proximity of all three of the urban constructs make the application of fires immensely challenging.

Fixed-Wing Challenges

Fixed-wing fires face multiple problems in the UOE including airspace constraints, susceptibility to air defense, target acquisition difficulty, trajectory interference, and collateral damage issues. The congestion found in cities makes urban AOs relatively small when compared with traditional military AOs. Concurrently, the airspace above them available for air operations is relatively small, and military air operations over urban areas quickly become as congested as the city itself. The multitude of Army, Air Force, Navy, Marine, international, civil, and interagency systems which use airspace must share this condensed environment. Additionally, CAS may require more airspace than normal interdiction missions since a preplanned, narrow ingress and egress route is not always maintained. Airspace requirements coupled with limited

airspace available may also mean a limited number of assets which can conduct CAS over the urban AO at a given time.

Another difficulty for air operations in urban areas is the threat of enemy air defense assets. While lower altitudes can give pilots a better opportunity for target acquisition and degrade enemy ground control intercept radar acquisition, it also places them in range of many unsophisticated enemy threats, such as small arms fire, and AAA and MANPAD systems, and makes laser self-designation impractical. Flying at higher altitudes can reduce the risk from surface to air defense by putting aircraft out of range of many of these threats, while at the same time providing more time to see and react to threats which can reach them. However, higher altitudes also mean that without local air superiority, CAS aircraft are in the heart of enemy radar coverage, and an active air threat or Surface-to-Air Missile (SAM) threat can disrupt the mission. In the UOE, both the airspace congestion and target acquisition difficulties can multiply threat effects creating a potentially lethal environment. The integrated air defense surrounding Baghdad in the 1991 Persian Gulf War provides an excellent example of such congestion. Baghdad, a city merely 30 kilometers across was defended by 380 AAA sites as well as 26 strategic SAMs and 32 tactical SAMs totaling 552 missiles (Winnefeld et al. 1994, 296).

The congestion and repetitive themes of the urban landscape can make aerial target acquisition in the UOE extremely challenging, especially if a pilot is receiving a verbal talk-on to the target, rather than given precise coordinates. Figure 2 shows an example of the visual complexity of the UOE with an overhead image of a small portion of downtown Baghdad, Iraq. Additionally, as if target acquisition was not difficult enough, CAS usually requires the pilot to visually identify the position of friendly forces

as well. While targeting pods have the capability to magnify the target area, the area of interest still has to be found. Fortunately, when available, the use of transmitted target and friendly coordinates, can drastically simplify this target acquisition process.

Figure 2. Baghdad Overhead View
Source: Google Earth, Version 4.0.2416; available from http://free.download.earth.googlepages.com/us-google-earth?gclid=CPnc4rq2u4sCFQ_iQQodAgj_Sw; Internet; accessed on 11 April 2007.

Once a target is acquired, trajectory interference must still be considered prior to attacking the target (reference figure 1). While a near-vertical impact angle will mitigate most trajectory interference problems, munitions limitations, threats and the target itself may dictate a shallower trajectory. An example of this would be attacking a bunker buried beneath a ten story building. Rather than attempting to penetrate ten floors and incurring excessive collateral damage, the munition's impact point may be placed at the base of the building at an angle so that it penetrates the bunker, and a small enough

munition may even leave the building above it intact. This placement will require a relatively shallow trajectory, and the pilot must ensure that other buildings or structures are not in the flight path of the munition. While this can be a difficult task, the flexibility inherent to aerial delivery makes it not only feasible but practical.

One more hurdle for conducting CAS in the UOE is the collateral damage inherent to the blast, fragmentation, incendiary, penetration, and cratering effects of conventional bombs. For decades, military focus was not only on accuracy, but on lethality. In most cases, that meant weapons with decisively destructive power, achieved through the use of area munitions or large quantities of high explosive, limited only by the weight an airframe or missile could carry. Unfortunately, in a high collateral damage area, such as a city, this concept does not readily apply. Up until 2002, "the smallest satellite-guided bomb in the Air Force arsenal weighed a whopping 2,000 pounds--enough to destroy a four story building" (Jaffe 2006). The US experience in the cities of Iraq has changed the Air Force focus, and today there is a fervent need for smaller, "focused lethality" precision weapons. In response, the Air Force has put satellite guidance, JDAM kits on 500-pound munitions, and has used these with good success. However, the ability to destroy only one corner of a small building without significant collateral damage to the rest of it, or to buildings across the street is difficult to achieve with even a relatively small 500-pound bomb or warhead, and without exacting precision. It is for this reason that the Air Force has accelerated the development of smaller weapons specifically for use in urban areas.

Field Artillery Challenges

> Targets within “urban canyons” pose a particular set of challenges and, until recently, were almost the exclusive fires domain of the Air Force or Army helicopters. (Kinne et al. 2006, 17)

The UOE also creates specific difficulties for precision FA, including trajectory interference, attack axis limitations, targeting complexity, and collateral damage issues. When looking at projectile trajectories, the vertical dimensions of urban infrastructure are much like firing into mountainous terrain, except very much compressed. Just as with fixed-wing munitions, the flatter the munition’s trajectory (due to either system limitations or due to distance), the more chance there is that vertical infrastructure will impede the flight path (Reference figure 1). Solutions to this problem are not only limited to getting a steeper trajectory, they also center around the ability to change the attack axis, especially in the case of tall buildings. For the most part, Army FA is a fairly physically fixed asset when it comes to responsive fires. This means that while FA can and does move, they cannot responsively change their axis of attack in a short period of time (for example, to hit the right side of a building 30 kilometers away versus the front). This fairly fixed axis of attack can also limit FA due to munitions effects. Impact error tends to be greater long or short of a target for most precision munitions. This is particularly true of GPS munitions, and their difficulties with elevation error. Assuming target coordinates are accurate, a munition on a 70 degree impact angle whose guidance system has an elevation error will impact long or short of the target. The only way to mitigate this (other than getting a better elevation solution) is to increase the impact angle of the munition close to vertical so that elevation is not a factor. This can be done by changing the range of the shot to create a higher trajectory, or by using a munition that

has the ability to shape its trajectory. Without this capability, collateral damage can only be mitigated by changing the axis of attack to put vulnerable areas (schools, mosques, and others) to the left or right of a munition's flight path. Additionally, the ability to hit the side of a building at a relatively shallow impact angle can be as important as hitting the top, for example when trying to destroy a bunker underneath a building. Under the restricted rules of engagement normally found in urban areas, the inability of a FA system to rapidly change the axis of attack or alter its impact angle may limit when a system can be used. Although not a complete solution, the Army is fortunately pursuing upgrades to most of its precision munitions which allow vertical trajectory shaping.

Targeting is another area of limitation for FA. Currently, FA precision capable systems are unable to self-designate, but rather rely on a forward observer or controller to provide coordinates or designate the target for laser guided munitions. Using a secondary designation source is inherently a more complicated and more time-consuming process than self-designation, and GPS guidance currently has no capability to designate moving targets. One last issue which ground-based fires contend with is the same as airborne fires--collateral damage. Until 2005, the limited number of Army precision fires systems with precision warheads restricted the options available to commanders for employment in urban areas.

> Large bursting radii and several variants of munitions dispensing an extensive volume of submunitions generally characterized the FA arsenal of rockets and missiles during the Cold War era. In fact, the enemy in Operation Desert Storm (ODS) called MLRS "Steel Rain" because of its volume, distribution and effects on them. The enemy was describing MLRS dual-purpose improved conventional munition (DPICM) sub-munitions dispensed by the hundreds across large areas of the desert. (Kinne et al. 2006, 18-19)

It was not until OIF that the need for a single explosive, or "unitary" warhead, rather than submunitions, became readily apparent, and the Army accelerated development of GMLRS Unitary and ATACMS Unitary. These munitions provide the Army with a point precision capability readily applicable to the UOE.

Fixed-Wing Precision Munitions

The need for improved accuracy both in ground-based and air-based fires has always been driven by the dream of "one-shot, one-kill" systems. Logistics, collateral damage concerns, and the ability to engage and kill faster than the enemy have all been a motivator for improving accuracy. In the field of precision munitions, the Air Force has led the way for the other services and the history of these munitions can be traced back to the necessity of the Army Air Forces to target bridges during World War II. This led to the development of the first guided bomb used in combat--the VB-1 AZON. This pioneering weapon was a radio-controlled, azimuth-only 1,000-pound bomb flown to the target by sight from the releasing aircraft (Werrell 2003, 139). Following World War II, few guided bomb improvements were made until the early 1960s, when the development of the electro-optical Walleye provided the capability of an autonomously tracking bomb. However, the Walleye's limitation requiring a low-level delivery in the heart of Vietnamese AAA gave way to the employment of developing laser technology usable at higher altitudes. The first operational implementation of laser guidance was the Paveway I LGB. It made its combat debut in May of 1968, with a 30-45 meter CEP, and marked the start of the Air Force precision munitions revolution (Werrell 2003, 149).

Since that time, LGB CEPs have steadily decreased with the introduction of Paveway II and Paveway III, achieving an extremely accurate CEP of 3 meters or less,

even against moving targets. However, their greatest limitation is the fact that infrared and laser acquisition and guidance systems can be seriously hindered by target area weather. In 2001, the introduction of JDAM, the first GPS-aided munition, fixed this and gave the Air Force an all weather capability, but at the cost of accuracy and loss of a moving target capability. JDAM series bombs have a CEP of approximately 10 meters, and are coupled with an Inertial Navigation System (INS) which keeps them on target in the event they lose the GPS signal. Since JDAM was developed, precision guided weapons have become the primary munitions the Air Force uses in combat.

Meanwhile, the Air Force has continued to improve on the JDAM concept, and two newly introduced munitions will play significant role in future urban operations. In October of 2006, the GBU-39/B Small Diameter Bomb (SDB) was first employed by Air Force aircraft (Weisgerber 2006). This newly developed munition was designed specifically to meet the needs of urban combat. The small, 250-pound size, coupled with wings, an improved GPS and INS guidance package, as well as cockpit selectable proximity, impact and delay fuze settings, and a 1.2 meter CEP, allow for greater flexibility, lower collateral damage and improved precision effects (Hewson 2004, 522; and AFPN 2006a). The variable fuze settings provide the capability to eliminate targets on the top of a building without destroying it, or determine how far the weapon will penetrate a building before it explodes. Pop-out wings give the bomb a standoff distance of up to 60 miles and the ability to be dropped while flying away from a target (Boeing 2007a). Future improvements will give it the ability to strike moving targets and replace the steel bomb body with a carbon-fiber focused lethality munition, giving it incredible

blast potential within a very small area (Boeing 2007b). Table 1 shows current Air Force fixed wing precision munitions capabilities (limited to weapons researched in this thesis).

Table 1. Current Air Force Precision Munitions

Munition	Guidance	Trajectory Shaping?	Size	Fuze	CEP
GBU-12 Paveway II	Laser	Vertical, Limited horizontal	500#	Impact, Delay	≤ 3m
GBU-38 JDAM	GPS/INS	Vertical, Horizontal	500#	Proximity, Impact, Delay	~10m
GBU-39/B SDB	GPS/INS	Vertical, Horizontal	250#	Proximity Impact, Delay	1.2m

Field Artillery Precision Munitions

The history behind US Army FA precision munitions began shortly after the invention of laser technology in 1960. Two civilian engineers working for Army Missile Command investigated the possibility of using a laser to designate targets for antitank missiles. Ironically, the results of their studies led to the development and fielding of the Paveway series LGBs (Redstone 2007). It was not until the early 1970s that the Army actually began development of a laser guided artillery munition, and the Cannon Launched Guided Projectile, later named M-712 Copperhead, was finally fielded in 1983 (Ness and Williams 2005, 580). Still operational today, Copperhead is an elongated 155-millimeter artillery shell fitted with a laser guidance package. In theory, Copperhead gives the Army a one-shot-one kill capability, but in practice and in combat, the complexities of its use have yielded mixed results with the National Training Center

reporting that the “target-hit success rate is only approximately 70 percent; some units achieve no hits” (Yager and Froysland 1997, 5). Hardware issues, targeting complexity, cost, lack of training availability, and stringent weather requirements among other problems, have made widespread use of Copperhead unpopular. However, as evidenced by its recent, albeit very limited use in OIF, under the right, controlled circumstances it can still be a lethal asset.

Although the Army continued some research in the area of FA precision munitions during the 1980s and 1990s, its focus on the subject waned, and the next FA precision munition was not fielded until 2002, with the introduction of the MGM-168E ATACMS Block IA Unitary. ATACMS is the Army’s long range surface-to-surface missile system, and traditionally has only been fitted with a cluster munition warhead for use against area targets. The ATACMS Unitary combines a single 500-pound high explosive warhead, a range increase to 300 kilometers, a GPS and Inertial Measurement Unit (IMU) guidance system (giving it a GPS-quality CEP), a near vertical impact capability, and a future upgrade to add proximity and delay fuzes to its current impact-only setting (Gourley 2006, 60). The Army followed the ATACMS Unitary by fielding an upgrade to its smaller and shorter range tactical Multiple Launch Rocket System (MLRS) missile in 2005. The resulting XM-31 GMLRS Unitary houses a 196-pound high explosive warhead, IMU and GPS guidance, impact and delay fuzing and is capable of a 2-3 meter CEP at a range of 70 kilometers. A future upgrade to the GMLRS Unitary will expand its urban capability with a much needed proximity fuze and trajectory shaping guidance for near-vertical impacts (Gourley 2006, 60).

In addition to its missile capabilities, the Army has continued to pursue precision cannon munitions and 25 years after the debut of Copperhead, it has just fielded a new 155 millimeter precision munition, the XM-982 Excalibur Unitary. Excalibur provides the Army a munition containing a single 50-pound high explosive unitary warhead, proximity, impact and delay fuzing, and GPS and IMU guidance giving it a 10 meter CEP. Excalibur has a current range of 24 kilometers, but future developments will seek to increase this to 40 kilometers through the addition of base-bleed technology (Kinne et al. 2006, 20). Base-bleed will introduce a composite propellant grain in the base of the shell which will produce an in-flight gas pocket dramatically decreasing aerodynamic drag (Fees 2006, 583). Ongoing programs continue to refine the accuracy and capability of both the ATACMS and GMLRS unitary missiles. Table 2 shows the current FA precision munitions capabilities.

Table 2. Current Field Artillery Precision Munitions

Munition	Guidance	Trajectory Shaping	Warhead Size	Max. Range	Min. Range	Fuze	CEP
XM-982 155mm Excalibur	GPS/IMU	Vertical	50 lb	23 km	8 km	Proximity, Impact, Delay	<10m
XM-31 GMLRS Unitary	GPS/IMU	None	196 lb	70 km	15 km	Impact, Delay	2-3m
MGM-186E ATACMS Unitary	GPS/IMU	Vertical	500 lb	300 km	70 km	Impact	~10m

CHAPTER 3

RESEARCH METHODOLOGY

The thesis primary research question was: What are the critical considerations for the joint employment of Air Force fixed-wing and Army FA precision munitions for urban fire support? In order to answer this question and the secondary supporting questions, a two-step research design was developed. First, a combination of primary and secondary data sources were drawn on to build expertise and provide data on the urban environment and the capabilities of both fixed-wing and ground-based fire support. Second, these capabilities were applied against a framework of considerations useful in urban JFS.

In gathering data on capabilities, the research was broken down into three parts: urban operations, fixed-wing precision munitions, and FA precision munitions. Secondary source data was drawn from joint and service doctrine, books, pamphlets, training manuals, a variety of periodicals, as well as theses, manuscripts, occasional papers, and other professional publications for the purpose of obtaining technical data, comparative systems capabilities and their applications. While the majority of the research was from secondary source data, information was drawn from the author's personal experience. Additionally, interviews or discussions were held with various Air Force and Army technical and tactical experts with the intention of including a practical look at the application of the systems.

Having established an experience base with precision munitions and urban concepts, a comparative analysis of both air- and ground-based systems was conducted. Specifically, the munitions and systems capabilities were compared and contrasted

against five different considerations applicable to JFS in the UOE. JFS employment considerations vary from conflict to conflict based on the operational and tactical situation and a multitude of other factors including the rules of engagement. Doctrinally, neither Joint, Air Force, nor Army publications give specific considerations for the application of JFS. The considerations of range, risk, responsiveness, accuracy, and flexibility were chosen by the author for this thesis based on recurring application themes discovered during the research. A primary source in the development of these considerations was a 2005 USAF Scientific Advisory Board report on Air Force Operations in Urban Environments. This report was produced by a panel of high-level experts from each of the services as well as from the civilian community, after extensive research involving visits and interviews with both Air Force and Army training and doctrine facilities. The report concluded "persistence, flexibility, responsiveness, and precision fires are traits of systems that can be successful in the urban environment" (USAF 2005). Considerations for employment were also based on fundamentals found in the Joint Time Sensitive Targeting Process (JP 3-60). The additional considerations in this thesis of risk, and range were subjectively added to form a complete picture necessary for employment at the tactical level. For the purposes of this thesis, these five considerations are defined as follows.

Range: The physical distance limitations of a munition and its employing and required supporting systems. Range limitations and capabilities can be defined by maximum or minimum range, and may include limitations due to fuel supply, logistics, ballistic trajectory limitations, designation systems, and communications. The primary

concern with range in the context of JFS in urban operations is the ability of a system to responsively deliver lethal precision fires.

Risk: Risk is based on the physical threat to the precision munition employment system from enemy action. This may be in the form of surface-to-air, air-to-air, air-to-surface, or surface-to-surface fires. Risk due to fratricide or collateral damage will be discussed under the definition of accuracy.

Responsiveness (and persistence): The ability of a precision munitions employment system to consistently react and employ munitions within a specified time. This definition takes into account considerations such munitions available, target acquisition and designation time and asset availability.

Accuracy: The ability of a precision munitions employment system to achieve the desired target effects, while mitigating undesired effects. Accuracy can be related to lateral proximity (CEP) to the desired mean point of impact as well as vertical proximity, the explosive power or destructiveness of a munition, and the ability to avoid collateral damage.

Flexibility: The ability of a precision munitions employment system to adapt to changing conditions and offer the commander a variety of options and capabilities. This may include, but is not limited to, altering targets, attack axis, and munitions effects, as well as providing synergistic affects such as ISR or battle damage assessment (BDA) capabilities.

The comparative analysis of these five considerations applied against Air Force fixed-wing, and Army FA precision munitions systems, is presented in chapter 4. Additionally, a generic attack guidance matrix provides a graphical breakdown of

employment considerations for fixed-wing and FA systems. The final part of the methodology for this thesis involved drawing logical conclusions from the comparison criteria. The thesis conclusions and answers to the primary and secondary research questions are presented in chapter 5.

CHAPTER 4

ANALYSIS

The research methodology described in chapter 3 provided an outline for analyzing the capabilities and characteristics of both fixed-wing and FA precision munitions systems. The following paragraphs apply the research information outlined in chapter 2 against the five considerations of range, risk, responsiveness, accuracy, and flexibility to answer the secondary research questions. Both fixed-wing and FA capabilities will be discussed as they pertain to each characteristic in the context of the UOE. This will provide a basis for the conclusions drawn in chapter 5, which will answer the primary research question.

Range

Chapter 3 defined range as the physical distance limitations of a munition and its employing and required supporting systems. Range limitations and capabilities can be defined by maximum or minimum range, and include both the ballistic ranges of the munitions as well as the maximum range the employing system can travel. Range can be limited by fuel supply, logistics, ballistic trajectory limitations, designation systems, and communications; however, the primary concern with range in the context of this thesis is the ability of a system to responsively deliver lethal precision fires in the UOE. Range limitations for aircraft are minor and generally due to threats (which affect responsiveness) rather than due to the physical range limitation of the aircraft. FA, on the other hand, tends to be limited by the physical ballistic range of its munitions, with minimum and maximum ranges, and the availability of three different systems

(Excalibur, MLRS, and ATACMS) to provide complete coverage playing critical roles. Although much of the argument about range limitations of the two platforms is not unique to the UOE, there are specific issues imposed by the compressed terrain, especially for FA, which do affect their operations.

Fixed-Wing Range

With combat ranges for fighter aircraft over 400 nautical miles, bombers in the thousands of miles, and the persistent availability of air refueling assets, the ability of CAS capable aircraft to range the AO is implicit (though not always easy). Recent US operations have shown very little, if any, evidence of air combat unavailability due to range limitations. What occurs more often is slowed responsiveness at longer ranges (long range, ground alert CAS for example), or a drop in persistence, or on-station time due to fuel limitations, and these factors are not unique to the UOE. However, the necessity for standoff range due to airspace and threat congestion, and the impact of decreased communications ranges are specific to the UOE, and are important factors.

Fixed-wing standoff range is a product of a weapon's ballistic range, target acquisition range, and target designation range. While LGBs have limited standoff potential due to target acquisition, and laser designation requirements (without a ground designator), "fire and forget" weapons, such as GPS-aided munitions, have the potential for much greater standoff ranges since visual target acquisition by the aircraft is frequently not necessary, and coordinates are used rather than laser designators. For free-fall munitions the maximum ballistic range of a precision bomb carried by fixed-wing aircraft is determined by the aircraft parameters at employment. The higher and faster an aircraft is at employment, the greater the range of the munition. In the case of JDAMs

and LGBs, their maximum ballistic range is usually between 5 to 15 nautical miles, though LGB maximum employment range may be further limited by the need to acquire and lase the target. The GBU-39 offers increased capability in this area with its pop-out wings giving it a range of up to 60 nautical miles. It is compatible with every US fighter and bomber aircraft, is already in use on the F-15E, and will soon be fielded on the F-22 and F-16. Additionally, the Air Force is currently testing add-on wing kits for JDAM which could extend its range out to at least 24 miles (Boeing 2007c).

Standoff range also provides the capability to avoid congested airspace. With each of the services avidly pursuing the acquisition of their own UASs, the challenge of increasing airspace congestion for MOUT is a real concern. Everything from handheld to strategic UASs are in development or already fielded. These assets, along with manned fixed-wing and rotary-wing aircraft, missiles, and artillery will all share the necessity and burden of having to operate in and around the focused limits of a city, and its limited airspace. However, UASs may provide some relief for another problem central to the UOE, communications range.

CAS is a radio intensive process. Whether using voice or data link messages, CAS requires the transmission of target, enemy threat, and friendly data between a forward ground or air controller and the attacking aircraft. In the UOE, ground-to-air communications required between a JTAC and the aircraft can be challenging. Loss of radio or datalink LOS to aircraft not directly overhead is exacerbated by urban canyons, buildings and other structures, and aircraft below the restricted horizon line of the city skyline may experience communications difficulties. This is especially true of UHF and VHF voice communications. Advances in communications technology, make other

options feasible though. “There are numerous examples [from OIF] of ground soldiers and Forward Air Controllers using SATCOM to communicate directly with in-bound aircraft to reprogram the target coordinates before the aircraft were within line-of-sight communications range” (Department of the Army 2006b, 66). However, this capability is currently limited to bombers, and with Satellite Communication (SATCOM) bandwidth already overloaded, tactical use of UHF and VHF is not likely to end anytime soon.

Field Artillery Range

In general, the Army’s tiered system of precision weapons (Excalibur, GMLRS, and ATACMS) provides good capability to range the AO, but there are limitations to this arrangement. Ranges for FA systems are broken into minimum and maximum ranges and are limited by both the logistical and tactical ability of the artillery system to move as well as the ballistic range of the munition. Additionally, communications range limitations may affect the ability of an engaged unit to direct fires. Table 2 depicts the unclassified ballistic munitions ranges for current precision FA systems and munitions.

A critical difference between fixed-wing and FA precision munition delivery systems is that the maximum ranges of FA systems are limited by the location of the launcher. A MLRS and ATACMS or High Mobility Artillery Rocket System launcher has a driving range of about 480 kilometers at a speed of 64 or 89 kilometers per hour respectively. The M109A6 Paladin 155-millimeter Howitzer, which shoots Excalibur, has a top speed of 64 kilometers per hour and a maximum driving range of just over 344 kilometers (Fees 2006, 984). While the system chasses have the capability to range a city, their speed, logistical trail, and the coordination required for movement and for airspace deconfliction makes repositioning in the UOE due to range limitations a slow and

sometimes complicated task--especially if the asset is not organic to the requesting commander.

FA ready to provide reactive support in the UOE will be fairly static in a Position Area for Artillery. Counterfire susceptibility, force protection concerns, logistical lines and minimum range limitations of MLRS and ATACMS, among other factors, will dictate specific position areas for artillery which will likely place artillery outside of city limits. In a low threat environment, such as counterinsurgency operations, FA placed within the confines of a city will likely collocate with other forces in a forward operating base, where it will remain fairly immobile due to force protection requirements. Such an emplacement inside a city will likely result in a tradeoff for capability, due to minimum range rings, attack axis limitations, and trajectory interference for low angle fires. These limitations may restrict FA's ability to range an entire city within its minimum and maximum ranges for the effects required. For example, a target demanding a small, focused blast on the far side of a city may only be in range of the ATACMS, which has a 500-pound warhead. Conversely, a target requiring a penetrating 500-pound warhead that is too close may be inside minimum range. A recent exercise with GMLRS Unitary at the National Training Center demonstrated this limitation when the system (which performed very well), "twice had to relocate to support units because the rocket requests were inside the munition's minimum range" (Wendland 2007, 4). Depending on the environment, relocating may not be feasible. If it is, the time it takes to relocate, reset, and coordinate new fire support coordination measures and airspace coordination measures may be tactically impractical (discussed further under Responsiveness).

As with fixed-wing operations, communications range in urban areas can be a challenge for FA, but is further limited by the fact that the communications are ground-to-ground rather than ground-to-air. Due to this fact, LOS will be further limited by the urban landscape, and additional measures must be taken to ensure communications are maintained. FM 3-06.11, *Combined Arms Operations in Urban Terrain*, addresses this issue. “Structures and urban infrastructure will reduce radio ranges. Use of wire, messenger, and visual signals should be increased. Antennas should be remoted on upper floors to increase their range” (2002, 10-16). Civilian telephone or cell phone systems may provide additional means for unsecured communications, or SATCOM may be an option, though the problem with bandwidth still exists. Additionally, the Army’s increasing use of UAS assets may offset some of this difficulty by giving fires an overhead observer, or communications relay. However, UASs will still contend with the same communications issues CAS aircraft have, and the additional third-party coordination required is inherently more complicated, and could slow responsiveness.

If precision FA is going to be effective in the UOE, its placement will be a critical, deliberate and difficult process, and though its fixed ballistic range can be a limitation, it is also a strength. FA systems have excellent standoff capabilities which generally exceed that of fixed-wing aircraft. This is a crucial factor when considering the implications of employment such as risk.

Risk

Risk is inherent in nearly any military operation, and the application of joint precision fires in MOUT is no exception. Both aircraft and FA can be threatened by enemy action. Chapter 3 defined risk as being based on the physical threat to the

precision munition employment system from enemy action in the form of surface-to-air, air-to-air, air-to-surface, or surface-to-surface fires. Risk due to fratricide or collateral damage will be discussed in this chapter under “accuracy.” While much of the argument of risk is not unique to urban operations, there are particular challenges with risk faced by the use of JFS in this environment. Of particular importance are the effects of threat congestion and threat identification, which can occur across the spectrum of military operations.

Fixed Wing Risk

Despite the new counterinsurgency threats which Army FA now faces in the Global War on Terror, threats opposing fixed-wing CAS have remained nearly unchanged, though they have lessened. Conventional military capabilities remain the only tools available to effectively threaten CAS in the UOE, regardless of the type of conflict. Consequently, threats to fixed-wing CAS in the UOE come in the form of tactical aircraft, and surface-to-air threats, such as tactical and strategic SAMs, AAA, or small arms fire. Due to the potentially devastating impact that these air defense threats can have on counterland operations, such as CAS, it is rarely conducted without air superiority, or without support from Suppression of Enemy Air Defense (SEAD) or air superiority assets. While air-to-air threats are definitely a concern for CAS in general, the distinction the UOE offers is the density of the surface threats, and the ability to identify and separate these threats from the population.

The inherent geographical density of the UOE provides an enemy a concentrated area to defend and focuses air defense. While small arms fire, MANPADs, and small AAA threats may be avoided by flying above them, the extended ranges of tactical and

strategic SAMs can pose a problem. Generally, individual older SAMs are a low to moderate threat to CAS. However, fourth generation SAMs, such as the SA-10/20, or multiple older SAM systems in close proximity can pose a more significant threat. The example of the 552-missile air defense around Baghdad discussed in chapter 2 lends itself to this discussion. An active missile engagement zone (MEZ) containing dozens of overlapping missiles, such as the "SuperMEZ" around Baghdad, poses a high threat and an obstacle to conducting CAS. Though not an urban example, the Israeli Air Force experience in the 1973 Arab-Israeli War also typifies the risk inherent to conducting CAS without air superiority, and within a concentrated enemy air defense umbrella. During the first twenty-seven hours of the war, the Israeli Air Force lost thirty planes, and of those that survived, the air defense "forced [Israeli] pilots to drop their bombs in support of ground troops at safer distances, and they frequently missed target altogether" (Gawrych 1996, 33, 40).

The abundant availability and affordability of older SAMs and the proliferation of fourth generation SAMs along with global urbanization makes encountering another SuperMEZ an increasing probability. Threats such as these must be suppressed or destroyed, or else substantial risk must be accepted in conducting effective CAS in such an environment. However, as JP 3-09.3 describes, "the [urban] terrain may limit suppression options. If the enemy air defense threat is significant, air support may be limited until the threat is reduced" (Department of Defense 2005, III-18, V-47). New and emerging technologies like stealth and standoff capabilities, such as seen in the F-22 and GBU-39/B, will help mitigate this risk in the future. However, the immediate reality is that only small numbers of CAS-capable aircraft have these technologies as of yet, and

air superiority is an essential prerequisite to obtain acceptable risk for CAS against a well equipped enemy.

Field Artillery Risk

Unlike the risk facing fixed-wing employment, FA risk is a more dynamic equation and heavily depends on the type of operation being conducted. FA may face conventional threats from enemy indirect fire, counterfire, infantry or mechanized forces, but may also face unconventional insurgent attacks, and threats to its logistical supply lines. Risk to FA during MOUT will likely be a direct result of its position (within or outside a city), and risk will probably be a tradeoff for capability.

Like other weapons systems, FA is ineffectual if it cannot range its target, and risk to FA during MOUT may be linked to standoff range and range limitations. Like most other activities in the UOE, the congestion, reduced LOS, intermingling civilian population, and reduced engagement ranges are a restrictive factor and make FA emplacement within a city a risky prospect. Because of this, FA will likely be placed outside a city in high-threat environments, or within a forward operating base in lower risk scenarios. However, this may come at the cost of ability to range the entire AO. For example, the city of Baghdad, Iraq is approximately 30 kilometers in diameter. In a city of that size occupied by the enemy, ATACMS and MLRS have the capability to engage targets throughout the entire city while maintaining standoff range outside enemy mortar and direct fire. Due to its reduced range, the smaller warhead capability of 155-millimeter artillery systems must accept either a limited engagement area or an increase in risk from enemy fire by emplacement within the city. Depending on the operational situation, this may or may not be acceptable.

Despite these issues, the standoff precision capabilities of FA systems can be very effective if properly placed, and can constitute an outstanding SEAD capability. In fact, FA was used in exactly this way during OIF. “Because the capital was heavily defended by antiaircraft missiles, SEAD by Army ATACMS was essential before fighter-bombers ventured into that airspace. Such missions proved to be effective in clearing the missile engagement zone around Baghdad” (Kirkpatrick 2004, 11). Although the vulnerability of ATACMS to fourth generation SAM engagement is a concern for the future, GMLRS unitary, Excalibur and even the coming Precision Guided Mortar Munition may be able to fill this gap and mitigate the risk to fixed-wing CAS in high-threat environments.

Responsiveness and Persistence

Responsive fires are essential to the movement and maneuver of ground forces, despite their environment. However, the congestion of the UOE forces closer and quicker engagements, making responsiveness an even more important capability. The ability of a precision munitions employment system to consistently react and employ munitions quickly can determine the outcome of a battle. In general, considerations, such as munitions available, command and control coordination time, and continued asset availability (persistence) are all factors to consider when characterizing the responsiveness of both fixed-wing and FA systems. However, most of these issues affecting responsiveness and persistence for fixed-wing and FA systems are generic, as they are applicable to any operating environment, not just to the UOE. Three issues, however, are specific to the UOE--coordination time due to communications range, availability due to range limitations or threats, and the effects of airspace congestion. The first two were discussed earlier in this chapter; however, airspace congestion and its

effects on coordination time were not. This issue is an important and specific part of MOUT because the number of assets sharing a small piece of airspace means coordination time and delays are likely to increase for both CAS and FA missions. Additionally, because the issue of asset availability is highly contested between the two services it also merits some discussion, and will be addressed.

Fixed-Wing Responsiveness

The density of the UOE has multiple effects on air operations. Threats are condensed, the proximity of friendly and enemy troops are condensed, and the airspace above them is condensed. Unmanned aircraft systems, fixed-wing and rotary-wing airframes conducting information operations, reconnaissance, attack, airlift, evacuation, and command and control missions must not only deconflict among themselves but also from friendly surface artillery, mortar and missile systems, and even civil aircraft, all while avoiding enemy threats. Target effects, munitions used, weather, friendly locations, and threats may all determine on-the-spot ingress, attack and egress directions. For example, the requirement to hit a bunker underneath the East side of a large building may limit the attack direction (depending on the munition). The UOE also forces closer engagements with the enemy, thus requiring fires to be used closer to friendly troops, where a parallel attack heading is preferred to reduce the risks of fratricide. These restrictions will dictate where an aircraft needs to fly, and the airspace it requires. The type of CAS platform also has an effect on airspace used. The availability of precision munitions to Air Force bomber aircraft now gives them a CAS capability, but the bonus of long loiter times and large munitions capacity comes at the price of limited maneuverability and sometimes larger airspace requirements. As a comparison, the

holding or reattack airspace required by a bomber can be over eight times the amount required by a fighter due to its reduced maneuverability.

As discussed under “Range,” Fixed-wing availability can be limited by the number and type of aircraft available, but is primarily driven by allotment. Because CAS is not an organic asset to a battalion or Brigade Combat Team (BCT) commander, asset availability is fundamental for responsive CAS. Twenty-four-hour dedicated CAS is resource intensive, and is subject to the priorities of the Joint Forces Commander. The Joint Forces Commander apportions CAS to the Combined Forces Land Component Commander. He, along with the Corps, Division, and BCT commanders will decide priorities for CAS and distribute it appropriately through the Air Support Operations Center down to the Air Liaison Officers at the battalion level. Just like support from a Fires Brigade, CAS prioritization and availability is entirely dependent on the situation, battle plan, and likely linked to the main effort. Because of this, it may be withheld from a unit by higher Army authority (CAS is not withheld by the Air Component Commander). Just like direct fire support, CAS distributed to directly support a brigade or battalion gives excellent responsiveness. Although this means CAS may not always be available to a BCT or battalion commander, the same concept readily applies to precision FA.

Field Artillery Responsiveness

Airspace congestion affects FA responsiveness due to the fact that airspace which is taken up by fighter, bomber, rotary-wing, or ISR aircraft is not available for use by FA without prior coordination. Airspace coordination measures, or fire support coordination measures (FSCM) are used to deconflict these fires. Airspace coordination measures are

defined as “measures employed to facilitate the efficient use of airspace to accomplish missions and simultaneously provide safeguards for friendly forces.” A FSCM is “a measure employed by land or amphibious commanders to facilitate the rapid engagement of targets and simultaneously provide safeguards for friendly forces” (Department of Defense 2001, 203). Condensed urban airspace will necessarily contain more assets than many other environments. More assets will mean more conflicts, and more coordination required for a given amount of airspace. The number of assets affected will also likely increase the likelihood that a request for airspace is denied. In any case, extended response times for coordination measures can be expected.

Beyond FSCMs and ACMs, the ground commander’s biggest limitation for fires responsiveness is the amount of coordination required to gain the support of, and employ an asset. By their nature, organic fires assets require less coordination, and are therefore usually quite responsive. Heavy BCTs will benefit enormously by gaining Excalibur as an organic precision asset. Responsiveness for heavy BCT fire missions within Excalibur’s capabilities should be excellent, and in many cases will probably exceed that of other systems. However, most Army FA precision munitions are not organic to BCTs. ATACMS and GMLRS are only found in the Division Fires Brigade, not within BCTs, and 155 millimeter (Excalibur) is only organic to Heavy BCTs (Department of the Army 2006a, 8-4). Because of this, BCTs will have to rely on the division Fires Brigade for all (or in the case of HBCTs, most) of their precision fire support. Additionally, some ATACMS may be under the control of the Joint Forces Air Component Commander for deep fires. This means that some or all of a BCTs precision FA will be predicated on whether or not there is direct or general support from the Fires Brigade. If direct support

or general support is not available, precision fires requests will be subject to the same type of delays as immediate CAS requests due to the approval process, and re-distribution of assets.

Accuracy

Under the traditional definition of accuracy, the need to deliver a weapon as close as possible to its target has been the driving force behind precision munitions development. However, the latest version of JP 3-0, *Joint Operations*, introduces a new element of operational design which necessitates looking at not only the CEP of a weapon but at the effect it will achieve, intended or not. For this reason, accuracy is defined not only by the lateral and vertical proximity of a weapon at impact, but also by its ability to achieve the desired target effects, while limiting side effects or collateral damage. In this context, the accuracy of even the limited field of munitions covered in this research varies dramatically based on individual capability.

Precision munitions create one of five effects: blast, fragmentation, incendiary, penetration, and cratering. In urban areas, considerations of the effects required and of those to be avoided are multiplied by the complexity and congestion of the environment. The employment of Joint Fires in this environment demands precision in terms of both CEP and the weapons effects. Targets can vary from the destruction of a small building or part of a large one, to the need to remove a sniper position on top of or in the middle of a civilian apartment building without harming friendly troops, noncombatants or damaging cultural buildings or infrastructure all within an extremely small area. Additionally, JFS is particularly difficult in this environment. "Historical studies prove that 90 percent of all urban engagements occur where friendly and enemy forces are

within 50 meters of each other, and that urban engagements using supporting arms occur with less than 250 meters between the same" (Department of Defense 2005, V-48). A stray munition or unintended effect can have greater repercussions due to the fact that "troop density for offensive missions in urban areas can be as much as three to five times greater than for similar missions in open terrain" (Department of the Army 2002, 4-9). Accuracy is absolutely necessary to engage targets under these conditions. The individual accuracy of fixed-wing and FA precision munitions is dependent not only on CEP, but also on warhead size, explosive effects, fuzing, trajectory, and guidance limitations.

Fixed-wing Accuracy

The specifications of current fixed wing precision munitions are listed in table 1 in chapter 2. Although the Air Force does not consider JDAM a precision weapon, its nominal 10 meter CEP coupled with a 500-pound size makes it a good, cost efficient weapon for certain applications in the UOE. However, a 10 meter miss distance in some urban settings where the street is only 7 meters wide can mean the difference between hitting the correct building or the building across the street. Collateral damage requirements may necessitate more precision, which may be gained by the use of an LGB or GBU-39/B SDB. Improvements to guidance packages, GPS solutions, and employment methods have reduced the CEP in follow-on GPS aided munitions, like the SDB, given the right conditions. Along with LGBs, these provide exceptional accuracy in terms of CEP and are ideally suited for use in the urban environment.

Recent Air Force operations in the cities of Iraq have generated a change in thinking about munitions capabilities in terms of size. Whereas the focus in cold war operations was on weapons with larger blast, fragmentation, incendiary or area effects

useful in full scale conventional warfare, the collateral damage effects of standard munitions like the 2,000-pound Mk-84 class bombs make them largely unusable in limited combat in the UOE. The operations the Air Force conducts today demand smaller munitions and an ability to focus weapons effects. 500-pound GBU-12 LGBs have been around for a while, but are more expensive than GPS-aided munitions and can be weather limited. The introduction of JDAM kits on 500-pound bombs, and the accelerated development and fielding of the 250-pound GBU-38/B SDB are the current solutions to these issues. However, even a 250-pound bomb is likely to destroy a small building, and that may not be acceptable, depending on the environment. The second phase of the SDB project will introduce a Dense Inert Metal Explosive enclosed in a carbon fiber bomb body, which will provide a highly focused blast, thereby reducing collateral damage effects. The SDB is a critical part of Air Force urban capabilities and, along with the explosive effects of the other fixed-wing precision munitions, provides excellent ability against most urban targets. However, warhead size alone is not the determining factor in achieving weapons effects. The ability to vary a munition’s fuze setting or trajectory can also drastically alter the effect it has on a target.

“During missions flown against Iraqi forces in and around Baghdad, the ASOC learned that Joint Direct Attack Munitions (JDAMs) with delayed fusing could be used effectively in urban operations and, properly placed, cause little collateral damage” (Kirkpatrick 2005, 11). Delayed fuze settings meant that the bombs buried themselves into the ground before detonation, thereby controlling the blast, fragmentation, and incendiary effects. Delay settings can also be used to crater roads (blocking escape routes), or penetrate bunkers or buildings before exploding. Impact fuzes provide good

capability to focus blast on structures, and proximity fuzes provide additional capability in urban areas by focusing fragmentation and blast effects on targets such as snipers or observers on the urban supersurface. Currently, JDAM can be fitted with all three fuze types, LGBs only with impact and delay settings, and the GBU-38/B SDB offers in-flight selectable delay, impact and proximity settings. Air Force LGB and JDAM fuzes are set prior to takeoff and generally not adjustable in flight. For this reason, aircraft may carry mixed loads of bombs with varied fuze types and settings for different capabilities. The wide array of available fuze settings certainly provides diversity, but the ability to change a weapon's attack azimuth and impact angle is equally as important.

Trajectory shaping in the context of this thesis is the ability to manipulate a munition to impact a target at different vertical and horizontal angles. This improves accuracy by focusing the munition's blast and fragmentation effects where you want them. The example from chapter 2 of targeting a bunker underneath a building demonstrates this point. From a fixed-wing perspective, trajectory shaping is the result of either release parameters from the aircraft, or the guidance capability of the munition. While release parameters can determine impact angle to a certain degree, the capability of JDAM and SDB guidance systems to fly themselves to a target from a certain azimuth at very shallow to near vertical angles is highly applicable to urban areas. Hitting a specific side of building (rather than the top) can focus effects where desired and significantly decrease collateral damage. Both JDAM and SDB have this capability. For JDAM, "the guidance law continually computes the optimal trajectory from the current position to the target to achieve an impact vector at the planned impact point, with the planned impact angle and impact azimuth, at the highest possible velocity" (Globalsecurity.org 2007c).

This ability has incredible potential in the UOE; however, the different guidance systems each have certain limitations.

Most of the precision munitions discussed in this research use GPS for primary guidance, and GPS has distinct limitations. These issues are discussed in this chapter under GPS Accuracy. Laser designation is the other type of munition guidance covered in this research and it suffers limitations of its own, including target visibility, reflectivity and transmissivity when used near windows and the podium effect.

LGBs are limited by target area conditions which affect the laser itself. "Cloud cover and precipitation as well as battlefield conditions (smoke, dust, haze, and other obscurants) can seriously degrade laser effectiveness" (Department of Defense 2005, III-19). Congestion is again a major factor in the UOE. The close proximity of structures and targets means that dust and smoke from previous weapons impacts can easily obscure a target or interfere with laser guidance. Windows also cause difficulties for lasers in the UOE. Research done by the RAND Corporation in 2000 summarizes this problem well.

> If the glass is in place, it is likely to reflect a great deal of the laser energy away from the designating platform and toward nontargeted areas such as streets, especially at steeper designation angles such as those required to attack the lower floors of city-core buildings. If the glass is not in place, the laser energy will simply pass through the window and little, if any, will be reflected back out the window at angles useful for incoming weapon guidance. (Vick et al. 2000, 114)

Additionally, targets self-lased by aircraft dropping LGBs must contend with the fact that the aircraft is moving at around 400 nautical miles per hour. After bomb release, the aircraft will often fly past the target before bomb impact due to its faster speed. On vertical structures, this means the laser spot will follow the face of the building closest to the aircraft whether the aircraft flies over the target or offsets it. When targeting an impact point on the roof of a building, the issue is inconsequential since the LGB will

usually retain an unobstructed view of the laser spot. However, when targeting the side or base of a building, the laser spot may pass out of the LOS of the LGB seeker. This is called the podium effect (reference figure 3). The laser could also be obstructed by other buildings if the lasing aircraft is offset too much. While this limitation is not necessarily specific to urban areas, the preponderance of built up structures makes it an important factor. As a solution, off-board designators, such as UASs or other aircraft can be used to alleviate this problem, but their use requires additional coordination and thus increases targeting complexity.

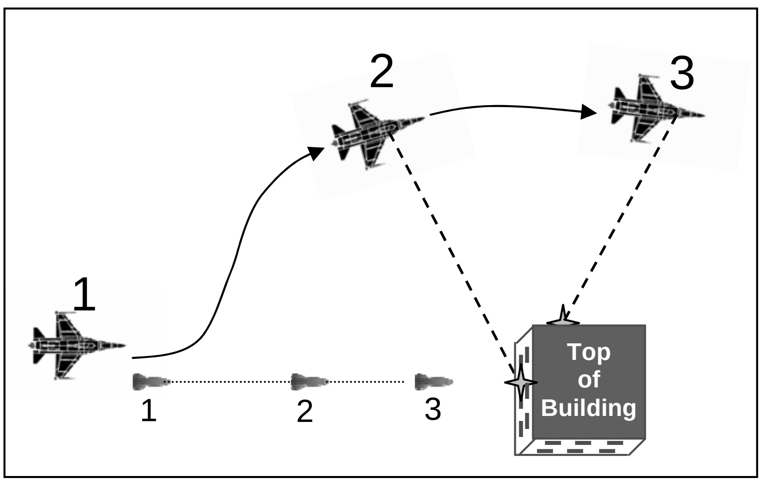

Figure 3. Podium Effect

Field Artillery Accuracy

The specifications for current Army FA precision munitions are listed in table 2. These munitions have CEPs nearly identical to those found in fixed-wing precision munitions. The nominal 10 meter CEPs of ATACMS and Excalibur mean they have the same accuracy limitations JDAM has with collateral damage. However, the GMLRS Unitary has the ability for a more precise CEP, given the right conditions. It is important

to note, though, that FA's only 2 to 3 meter capability is tied to a 200-pound warhead. Outside of CEP, warhead sizes and munition effects for Army precision munitions are well suited to MOUT. While the 250-pound GMLRS Unitary and 500-pound ATACMS offer blast accuracy comparable to fixed-wing munitions, the 50-pound, 155 millimeter Excalibur rounds in particular offer the ability to engage large room size targets, rather than just buildings due to their smaller size. The use of artillery during OIF provides an example of the usefulness of smaller munitions. In the battle for Fallujah, it was found that "proximity-fuzed artillery was effective against rooftop threats and danger close missions were the rule and not the exception--the 155mm and 120mm fires routinely were within 200 meters of friendly forces" (Rabaut 2004). Using larger munitions for this task would require increased distances from friendly forces and likely result in the destruction of the buildings beneath the blast. Excalibur will not only be able to engage rooftop targets with its proximity fuze, it will be able to target a specific building with a single shell, and reduce the distance required between friendly forces and the target.

Army FA fuzing and trajectory options generally have the same application in the UOE as fixed-wing munitions; however, actual munitions capabilities are more varied among the three munitions. ATACMS has trajectory shaping, but no proximity or delay fuze option. The high-precision GMLRS Unitary currently has no trajectory shaping option and no proximity fuze, while Excalibur, being the newest munition, has all the options. Upgrades to GMLRS Unitary and ATACMS will expand these capabilities by "shaping their trajectories to provide a nearly vertical attack angle, as well as adding tri-mode fuzing options (proximity or airburst, point detonating and delay) (Gourley 2006, 60).

Since all FA precision munitions systems use GPS, guidance system limitations are discussed in the next section, GPS Accuracy. In addition to those limitations, a notable drawback of FA precision munitions is their inability to shape their trajectories horizontally. This significantly reduces accuracy in terms of options to reduce collateral damage and to obtain only the desired effects. For example, the only way FA precision munitions could engage a bunker or basement built under the far side of a large multistory building would be by attempting to penetrate the roof and multiple floors, or by taking the time to redeploy assets across the operational area to engage the target on the opposite azimuth. In most cases this will prove impractical or infeasible.

Global Positioning System Accuracy

Both the Air Force and Army are increasingly reliant on GPS as a primary guidance source for much, or in the case of the Army, all of their modern precision munitions capability. Although any weapon system has factors, such as operator training or hardware limitations which affect accuracy, GPS-aided munitions are unique in a couple of areas. They are subject to the accuracy of fixed target coordinates, and they rely on a space-based guidance signal whose influence is largely outside the control of the operator and can significantly affect performance. The accuracy of GPS precision munitions is only as good as the target coordinates, and it is further limited by the accuracy of the signal being received from the satellites. It is for this reason that a GPS munition which has the capability to obtain a CEP of 3 meters under optimal circumstances may perform worse under conditions involving signal interference. While the GPS munitions covered in this thesis all have backup IMU or INS guidance systems, all of the munitions suffer a decrease in accuracy in these modes. With GPS as a primary

guidance source, there are definitive issues which affect signal accuracy, both in determining coordinates of the target, and in guiding the munition to those coordinates. Among these issues are Target Location Error (TLE), datum accuracy, space weather impacts, visibility and geometry, and signal bounce.

Both the Air Force and Army use multiple systems to obtain target coordinates and many of these systems use GPS to derive these target coordinates. Therefore, inaccuracy in GPS-aided munitions can be the result of poor target coordinates, or TLE, or it can be due to guidance errors obtained by the munition itself. The first issue for TLE is target location system inaccuracies. Target location systems provide target coordinates which are used for engagement. A target location system which has a longitudinal error due to signal interference will produce imprecise coordinates. As a result, a GPS munition with a clear signal that is programmed with those faulty coordinates will miss the target. An additional difficulty with plotting coordinates falls in the fact that, GPS coordinates are plotted according to latitude and longitude, and not all latitude and longitude grids, known as datums, are the same. With over 100 different datums in use today, using the wrong one to provide or receive GPS coordinates can result in a TLE of over one kilometer--a potentially devastating error in close combat. The second TLE issue for GPS munitions is the fact that they cannot engage moving targets. GPS-aided munitions receive a target coordinate handoff at launch, and go after those coordinates with no in-flight updates. Targets which move during the weapon’s time of flight are missed. While it may be possible to estimate coordinates to drop a weapon in front of a slow moving vehicle, the speed at which most vehicles move and turn, makes this impracticable. This is a significant limitation in the UOE.

Assuming the correct datum is used, then TLE and munition guidance system inaccuracies can result from bad GPS signals, which can be distorted in several ways. First, "the extremely low power levels of the GPS signals transmitted from space can be overwhelmed with local or mobile jammers. We found this out first-hand during OIF in 2003 when Iraqi forces used GPS jammers against our forces in Baghdad" (Department of the Army 2006b, 117). While GPS-aided munitions can use anti-jamming techniques such as an internal INS or IMU for backup guidance, loss of a signal may result in some loss of precision.

Outside of jamming, GPS signals are affected by multiple factors, including space weather and dilution of precision due to satellite geometry and visibility (LOS between receiver and satellite). Space weather and the resulting electromagnetic interference or "ionispheric scintillation" can affect all communication and navigation systems to some extent. This interference "can cause a GPS receiver to lose signal lock with a particular satellite [and] the reduction in the number of simultaneously useable GPS satellites may result in a potentially less accurate position fix" (Department of the Army 2006b, 32). The electromagnetic interference of space weather can have a drastic impact on the accuracy of GPS munitions. Unfortunately, while solar weather does have patterns, it can be as unpredictable as terrestrial weather, and its impact may be unavoidable. A more predictable influence on GPS precision is the effect of satellite geometry and visibility.

Precise GPS guidance relies on using signals from four satellites in different geometric positions to determine a precise position. Three of these provide latitude, longitude and elevation, while the fourth provides correction for timing errors inherent to the internal clocks of GPS receivers. In order to receive precise coordinates, a receiver

must maintain LOS, or visibility, with each of the satellites, while using signals from satellites spaced far enough apart to allow good resolution--also known as geometry. Four satellites directly overhead of a receiver will provide excellent visibility, but decreased precision due to geometry. However, four satellites spread across the horizon will give excellent geometry for precision, but the visibility of some of the satellites may be blocked by buildings or terrain, resulting in an imprecise location. Additionally, receivers may receive multipath signals. “Multipath results from signals being reflected off of objects in the vicinity of the receiver” (Department of the Army 2006b, 105). Although GPS receivers usually employ techniques to minimize this, the innumerable structures which create urban canyons provide a perfect environment for multipathing (Department of the Army 2006b, 105). While GPS munitions themselves will undoubtedly maintain an unobstructed LOS to the satellites, roving GPS ground receivers in urban areas (used to derive and transmit target coordinates), may be significantly affected.

Solutions to the problems of GPS inaccuracy are numerous, with new developments continually being fielded. Many of these solutions use ground stations to transmit correction messages for known signal inaccuracies. Differential GPS is an example of one of these. “The one error correction from the differential station corrects for all the errors in the GPS signal: receiver clocks; satellite clocks; satellite position; ionospheric delays; atmospheric delays” (Department of the Army 2006b, 112). Ground stations, are not the magic fix, however, as they must also be in range of and within LOS of a receiver, and can be jammed or destroyed. Despite the improvements, GPS still has its challenges in the UOE including receiver LOS, multipathing, and jamming, and a GPS

munition's CEPs will vary due to these issues. It is for reasons such as this that the Air Force, in particular, still refers to GPS aided munitions as "accurate," rather than "precise."

Flexibility

The ability of a precision munitions employment system to adapt to changing conditions, and offer the commander a variety of options and capabilities is increasingly important in ongoing urban operations. This may include, but is not limited to, altering targets, target designation methods, attack axis, and munitions effects, or providing synergistic capabilities, such as on-board ISR and BDA. Although this topic is largely centered on the employment system, rather than the precision munition itself, system capabilities are very relevant, based upon the environment. A repetitive theme with the UOE is congestion. The targets, enemy and friendly forces, protected areas and structures, airspace and military assets are all in close proximity. Flexibility allows JFS more options for attack, more options to mitigate damage, and more options to reduce the number of assets required to operate in the restricted conditions that are a function of this environment.

Fixed-Wing Flexibility

Fixed-wing aircraft offer remarkable flexibility in the delivery of precision munitions in urban operations. A fighter or bomber weapon system provides multiple capabilities for JFS in the UOE, including target designation capabilities, variable attack axis and munitions effects, and multiple synergistic capabilities.

Designating targets for CAS is usually the job of a JTAC. This is done be either acquiring low-TLE coordinates for the use of JDAM, and transmitting them to the aircraft, or by giving a verbal talk-on using lower quality coordinates. In the case of LGB deliveries, the JTAC, or his Joint Fires Observers have the capability to lase the target, but in an urban environment the complexities of coordination, LOS and weapons effects usually restrict that. Offsetting this is the fact that all precision-capable fixed-wing aircraft have the capability to self-designate targets for LGBs using their targeting pods. Additionally, aircraft equipped with an advanced targeting pod (most employed in theater have this) also have limited capability to derive GPS quality coordinates for JDAM employment. This provides fixed-wing aircraft three distinct capabilities. First, an aircraft can deliver precision munitions after receiving only a verbal talk-on (passing precise coordinates is not required). Second, under Type 3 CAS, where the JTAC gives the pilot temporary weapons release authority, fixed-wing aircraft can engage multiple targets without the need for individual target coordinates. Third, fixed-wing aircraft using LGBs have the capability to engage and kill moving targets (given good weather).

These are exceptional capabilities for JFS in an urban fight, where it is very likely that the JTAC and his joint fires observers will be unable to see all their targets. More likely, they may only see one tank, armored vehicle or truck, rather than the three or four which are there. In fact, the urban landscape may interfere so much that Army doctrine states that “lack of ground observation may require the use of airborne FAC” (Department of the Army 2002, 10-18). The flexibility inherent to the fixed wing platform makes the engagement of multiple targets possible, even if they move out of sight of friendly forces on the ground.

After a target has been designated, fixed-wing capabilities to alter munitions effects are a key part of flexibility. The ability to rapidly alter attack axis has been discussed several times in this research, and remains a viable part of engagement in urban operations. In addition to this is the ability to alter fuzing, and to select munition size and type for engagement. A fixed-wing aircraft is limited to employing the munitions loaded on the aircraft, and depending on the weapon, the fuze setting may not be changeable in flight. However, aircraft often fly with mixed loads to facilitate engaging different targets, and the availability of multiple aircraft may provide a variety of weapons for a specified task. An example of mixed-loading was seen in an air strike in Iraq against Abu Musab al-Zarqawi on 7 June 2006. The aircraft "dropped two precision-guided 500-pound bombs, a GBU-12 laser-guided bomb and a GBU-38 JDAM, destroying an isolated terrorist safe house, where al-Zarqawi and other terrorists were meeting" (AFPN 2006b). Had al-Zarqawi attempted to escape the safehouse in a vehicle, the laser-guided GBU-12 could have been used to engage it. If the target had been obscured with weather, the GBU-38 still would have worked. Another example is current combat missions in Southwest Asia, where F-15Es have been loaded for combat carrying JDAMs, LGBs, and SDBs giving them a broad spectrum of capability (Best 2007).

In addition to its targeting capabilities and weapons load, fixed-wing precision munitions platforms provide additional synergistic effects to MOUT. Specifically, they can provide immediate BDA and munitions effects assessment if the target is out of sight of the JTAC or fires observers. Additionally, fixed-wing aircraft have the unique capability to threaten the use of precision weapons, without actually employing them--called a "show of force." This offers the ground commander an additional option to

mitigate unnecessary destruction or damage. A perfect example of a combination of fixed-wing synergistic effects is an excerpt from the 21 April 2007, SAF/PAO airpower summary for Southwest Asia. “Other F-16s provided a show of force for Iraqi police who found themselves with a large gathering of anti-Iraqi forces around them. A JTAC judged the jets’ show of force was successful and no attacks on the police were reported. The pilots also reported an IED hotspot in the surrounding area and passed the coordinates to the JTAC” (2007). The ability self-designate and deliver precision munitions with extremely accurate effects, or just threaten its use while providing on-board non-traditional ISR and targeting capability makes fixed-wing aircraft extremely flexible.

Field Artillery Flexibility

FA also provides precision munitions flexibility, specifically in the area of munition effects through its ability to employ an extensive supply of 50-pound, 200-pound, and 500-pound precision munitions. The Army’s tiered approach to the application of FA precision munitions provides an excellent spectrum of capability. The already fielded 155 millimeter Excalibur, in particular, enables all-weather, small warhead precision engagement indifferent to air defense threats--a capability currently unmatched by fixed-wing CAS. Currently, the smallest precision munition that fixed-wing CAS employs is the 250-pound SDB (other than AC-130, and it is vulnerable in anything but a low threat environment). With properly placed position areas for artillery, Fires Brigades providing direct support can offer the BCT commander all three precision munitions to support the fight.

Beyond munitions effects, however, flexibility is not a strength of FA. Its precision munitions systems rely completely on forward observers or UASs for target

designation, BDA and munitions effectiveness assessment. This can restrict FA's use in the complex and congested urban environment. For example, "A common ROE is to require the engaging asset to positively identify a target prior to engaging it. ATACMS [along with GMLRS and Excalibur] have no capability to comply with this unless the ROE allows a third party to positively identify a target for a GPS-guided munition" (Rogers 2006, 57). Additionally, FA precision munitions currently have no capability against moving targets, though this capability is being avidly pursued.

Attack Guidance Matrix

Each of the considerations of range, risk, responsiveness, accuracy and, flexibility plays a unique part in the decision cycle for targeting staffs and commanders. Identifying each of the considerations, as it applies to the munitions and its systems, can be a difficult task. One of the more common tools for simplifying this decision process is the use of an attack guidance matrix. In his 2006 thesis, "Army Tactical Missile System and Fixed-wing Aircraft Capabilities in the Joint Time-Sensitive Targeting Process," Major Henry Rogers developed a generic Attack Guidance Matrix to compare and contrast ATACMS and fixed-wing operations in the time-sensitive targeting process. Table 3 is a copy of Major Rogers' matrix modified for this thesis to compare the application of FA and fixed-wing precision munitions in urban operations. It is meant to assist decision making through the use of questions which are either answered Yes or No or on a numerical scale from one to ten with ten being the best or most applicable. The primary reason it was used is that all combat situations are not the same. The applicability of a system to the UOE will largely depend on the situation, and there are a multitude of factors to consider when employing JFS in the UOE. Some, all, or none may be applicable. The matrix

provides a graphical breakdown of employment considerations for fixed-wing and FA systems and provides insight into the conclusions drawn in this thesis in chapter 5.

Table 3. Attack Guidance Matrix

Urban Attack Guidance Matrix		
RANGE/ACCURACY	Fixed-Wing	FA
1. (Y/N) Does the weapon system have the range to hit the target? - Consider MLRS or 155mm for Min Range - Air Refueling assets available?		
2. (Y/N) Can the weapon system physically hit the target? - Moving target? - Coordinate Confidence? - GPS Jamming / GPS signal accuracy? - Attack axis limitation? - Trajectory interference?		
3. (1-10) Can the weapon system achieve desired effects? - Delayed/proximity fuzing, attack axis, specific impact conditions, penetrations? - Collateral damage constraints (warhead size, fuzing) - Specific trajectory requirements (shallow/steep)? - Communication limitations? - Fratricide possibility?		
4. (Y/N) Do target area meteorological conditions allow desired weapons employment? - Clouds, wind, thermal crossover?		
5. (Y/N) Can the weapon system comply with the Rules of Engagement? - Positive Identification required prior to release? - 3rd party verification exception for GPS guided weapon?		

RISK	Fixed-Wing	FA
1. (Y/N) Can the weapon system employ munitions with acceptable risk? - Enemy counterfire or air defense capability - Do weapons have standoff capability? - Does weapon system need SEAD support? - Is weapon vulnerable to any threat en-route?		
RESPONSIVENESS/PERSISTANCE	Fixed-Wing	FA
1. (Y/N) Is the weapon system available? - Consider weapon and fuzing requirements - Consider retasking, airborne alert, and ground alert		
2. (1-10) How quickly can the weapon system put effects on the target? - Airspace deconfliction (FSCM, ACM) - Time to reposition or fly within range?		
3. (Y/N or N/A) Are additional assets available (if required)? - Consider availability and time on station of SEAD, escort, and tanker assets		
4. (Y/N) does the weapon system have adequate on-station time? - Can it remain in the target area long enough for a reattack?		
FLEXABILITY	Fixed-Wing	FA
1. (Y/N) Can the weapon system self designate? - Lase itself or generate coordinates? - Will weather limit this capability?		
2. (Y/N) Can the weapon system provide ISR or BDA? - Will weather limit this capability? - Can FO provide this?		
3. (Y/N) Can the weapon system provide an immediate reattack? - Target moved, bad coordinates, effect not achieved?		
4. (Y/N) Can the weapon system provide reduced or non lethal effects (ie: show of force)?		

Source: Henry T. Rogers III, “Army Tactical Missile System and Fixed-Wing Aircraft Capabilities in the Joint Time-Sensitive Targeting Process” (Thesis, Army Command and General Staff College, Fort Leavenworth, KS, 2006), 60-62.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This thesis researched the capabilities of selected Air Force fixed-wing and Army FA precision munitions as they relate to JFS in the UOE. The intent behind this was to find out how Air Force fixed-wing and Army FA precision munitions may best be integrated and employed together for urban JFS. The primary research question was: What are the critical considerations for the joint employment of Air Force fixed-wing and Army Field Artillery precision munitions for urban fire support? Supporting this were secondary and tertiary questions, addressed throughout the thesis. Chapters 2 and 4 answered the first three secondary questions by explaining the UOE, how it differs from other environments, and how desired effects differ. The final question built upon the others and asked; what the unique advantages and disadvantages of the weapons systems were when applied to the UOE. It is answered below. However, in comparing the two systems, it is again important to highlight that it was not intended to single out one munition, system, or service as being better or worse than the other but to understand how the systems and munitions may be employed together in a joint fight. With this understanding, the analysis presented in chapter 4 centered on the thesis tertiary questions concerning range, risk, responsiveness, flexibility and accuracy, and supports the following conclusions.

The primary strengths of Air Force fixed-wing precision munition fire support in the UOE are flexibility and range. The primary weakness of fixed-wing urban CAS is the risk inherent to operating in anything other than a low threat environment. A single fixed-

wing aircraft has an unparalleled ability to quickly range the entire AO and deliver a diverse selection of munitions from nearly any direction or angle, with a variety of fuzing, and moving target capabilities. Furthermore that same aircraft can self designate its target, provide near real-time BDA and ISR while also offering the commander an option to show force, rather than just use it. However, the fact that the system is expensive, lightly armored, manned, has limited standoff range, and is not easily replaceable makes its use for CAS in a high threat environment a substantial risk. Among the other considerations, accuracy (effects capability), favored fixed-wing aircraft, but the fact that it is a distributed asset (unlike Excalibur) may make it less responsive.

The primary strength of Army FA fire support in the UOE is its ability to deliver precision fires without significant risk. The primary weaknesses of FA systems are range and flexibility. The standoff range inherent to Army FA munitions provides the capability to strike targets with minimal risk. Currently this capability is unmatched by any fixed wing asset, short of the SDB's standoff range. However, FA is limited by the fact that it achieves its ability to range an AO by proper prior placement of multiple systems, each with different munitions capabilities. Additionally, FA systems do not have the capability to self-designate targets, provide BDA or ISR, shape their trajectories horizontally, or attack moving targets. Among the other considerations, responsiveness tends to favor FA when operating as direct support, or if Excalibur is an organic asset to the BCT. Accuracy was both a strength and a weakness of FA. While Excalibur provides FA with a highly desirable, smaller munitions capability, the inability to attack from different axes limits when and where it will be used.

The research indicated that neither fixed-wing nor FA systems alone provide the optimal mix of capabilities for urban JFS. However, the systems' strengths can complement each other if used together. FA precision munitions can be used to mitigate the risk to fixed-wing CAS in a high threat environment, and Excalibur can be used to attack targets requiring a smaller warhead with good responsiveness. Fixed-wing precision munitions can be used where ISR or immediate BDA is required, or where unique target conditions require a specific attack azimuth.

These conclusions provided a thorough understanding of what is important in urban JFS, and along with the background from chapter 2, present the following solution to the primary thesis question. The critical considerations for the joint employment of Air Force fixed-wing and Army Field Artillery precision munitions for urban fire support are accuracy, and flexibility.

These two factors are critical because a weapon employed for JFS in the UOE must have the capability to create very specific effects while avoiding unwanted effects. This is a direct result of the density and congestion which define the UOE and set it apart from other environments. Close support requirements combined with the interfering proximity of the urban population, physical terrain, and infrastructure, result in significant weapons constraints. Weapons employment in the UOE can be restricted by a multitude of factors including the rules of engagement, public scrutiny, the Law of War, terrain complexity, troop proximity, and other collateral damage and civilian concerns. Commanders must consider whether a weapon is accurate and flexible enough to not only physically hit the target (moving or not), but whether it can do so from a specific impact azimuth and vertical angle, with an appropriately sized blast, using the best fuzing option

to achieve only the intended effects. Additionally, since the weapon system will use extremely limited, high-demand airspace above urban areas, commanders must also consider whether it has the flexibility to provide synergistic effects such as ISR, BDA, or nonlethal capability. Targets buried within urban canyons and extremely close to friendly troops must be successfully targeted and engaged, despite the fact that they are surrounded by innocent civilians, religious or cultural sites, and city infrastructure which cannot be harmed. Under these circumstances, accuracy and flexibility are absolutely critical for weapons system success.

Recommendations

It is clear from the research that specific weaknesses exist in the varying weapons systems. Fixes to many of the issues presented are currently being researched, developed, and tested. Information on upgrades to the existing weapons systems was presented in the text; however, several areas for improvement still remain.

Fixed-wing capabilities need to continue to focus in the direction of smaller, focused lethality weapons such as the SDB to meet the need of smaller targets. However, a gap still exists in the capability to engage moving targets under all weather conditions. Project development in this area needs to be continued, and this capability needs to be fielded. Additionally, the recent trend towards total reliance on GPS for a primary source of weapons guidance is of concern. Loss of this single-source guidance capability could seriously threaten combat effectiveness, especially in an urban environment. Alternative, autonomous guidance methods should be pursued.

FA upgrades are definitely advancing in the right direction with the introduction of tri-mode fuzing and vertical trajectory shaping. However, FA capabilities need to

focus on the ability to overcome their attack-axis limitations. Munitions with programmable flight paths for variable attack directions and impact angles need to be developed. Additionally, like fixed-wing aircraft, moving target capability needs to be developed, and a more focused lethality capability for ATACMS and GMLRS would provide additional options which take advantage of the extended ranges of these munitions.

For Further Research

As stated in the delimitations, the scope of this thesis was limited. The topics of Joint Fires and urban operations provide a plethora of research topics, many of which were not covered in this thesis due to time and space constraints. Among those topics, specific to JFS in the UOE, is the application of other weapons or weapons systems to the fight. Specifically, rotary wing aviation, UASs, AC-130 gunships, and less than lethal munitions and capabilities were not covered. However, they are viable precision systems which have outstanding applicability to urban JFS. Further research in these areas would expand on the conclusions drawn in this thesis, and perhaps discover further strengths and weaknesses in JFS capabilities.

Finally, it is understood that the author is not an artillery officer, or an Army officer. Because of this, there are bound to be opinions and perhaps even facts which counter the conclusions in this thesis. The reader is encouraged to engage with those arguments, and continue to research this topic, so that officers from all services fully understand the capabilities of these systems and are thinking jointly about how best to use them together to defeat the enemy.

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